Experimental Evaluation of a Digital Hydraulic Pumping System

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Abstract: *The field of digital hydraulics is in full expansion and a lot of research teams contribute to its development, in order to be competitive with classic hydraulic systems, and reduce the energy loses from the hydraulic systems. This article presents the experimental results for a Digital Hydraulic Pumping System (DHPS), with 4 pumps with fix displacement connected in parallel and the capacities of each pump is in the binary progression. The experimental results show that such a system can achieve 15 discrete values of flow, without hydraulic fluid throttling to achieve flowrates regulation. The system is tested using an application that can do an automatic test of the system using a excel file defined by the operator, and the results are showed live on the app screen as numeric values or as a chart.*

Keywords: *Digital hydraulics, hydraulic system, pumping system, programable logic controller*

1. Introduction

Hydraulic systems are vital for some fields like mining, construction, and manufacturing, but have a lot of energy loses due to hydraulic fluid throttling made by different hydraulic components in order to achieve good control and rapid response from the system. The energy loses due to hydraulic fluid throttling are a big disadvantage for the hydraulic systems and a big throwback for the worldwide direction to reduce the pollution and control the climate changes and global warming. Hydraulic systems lined up with the trend of pollution reduction by introducing equipment such as load sensing pumps but those are quite expensive and the investment is not worth it if the system does not require a multitude of fluid variations.

In recent years, the researchers from the hydraulic field have developed a new field that can align to the worldwide trend to reduce energy consumption and pollution, called digital hydraulics. The field of digital hydraulics is defined as a system that has discrete components and can actively control the output of the system [1].

Many of the digital hydraulic systems use on/off directional valves and they have various advantages, such as [2]:

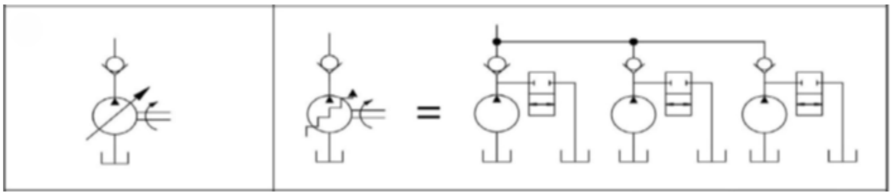
- More simple and cheaper directional valves;
- Simpler electronics;
- Decreased energy consumption;
- Increased life span of the directional valves;
- Higher flexibility;
- Easy connection with a Programable Logic Controller (PLC);
- Less sensitive to fluid contamination;
- Do not need a feedback for the spool position, like proportional or servo-valves do.

The digital hydraulic pumping systems concept is split between digital hydraulic systems in parallel, and high frequency digital hydraulic systems [3].

The first one uses codding methods such as Pulse Number Modulated (PNM), which uses the series 1, 1, 1, 1 … etc., and the Pulse Coded Modulated method, which uses the binary series (2^n, where n is the number of components, such as pumps or directional valves), and the Fibonacci series (this one is rarely used in systems presented in literature). The output flowrate for a parallel digital hydraulic system is the sum of the directional valves that are open.

The second one uses a single directional valve that has the capacities of high frequency switching of the spool between the open and close position, and uses control signal named Pulse Width

Modulated (PWM). The output flowrate of the high frequency digital hydraulic system is obtained by the open and close ratio periods made by the directional valve spool.



a) b)

Fig. 1. A) Analog pumping system; b) Digital hydraulic pumping system in parallel [4]

Figure 1 illustrates a comparison between the symbol of analogue pumping system with variable capacity and the symbol of a digital hydraulic pumping system.

Generally, in digital hydraulic parallel systems, the PNM coding method is not as used as the PCM coding method, because the first one needs a lot more components in its structure to achieve a decent flow variation. For example, a digital hydraulic system coded using the PNM method with 10 directional valves can achieve 10 discrete flow variations; instead a digital hydraulic system coded with the PCM method with 4 directional valves can achieve 16 discrete flow variations; so, it is more convenient to use the PCM coding method for space reasons.

In [5] authors have simulated, using Amesim software, the function of a digital hydraulic system with 4 parallel connected fix displacement pumps, having the capacities in binary progression, and this paper is a sequel of that paper and it comes with the experimental data for the simulated system.

2. Material and Methods

The Digital Hydraulic Pumping System (DHPS) investigated in this paper is designed to adjust the non-resistive fluid flow by independently enabling and disabling each pump to direct flow in the system or to the oil tank with the help of 4 directional valves and 4 check valves.

The DHPS hydraulic diagram is presented in figure 2 and is composed of:

- 4 fix displacement pumps with the capacities in binary progression (2, 4, 8, 16 cc/rev) marked as P1, P2, P3, P4;
- biaxial three phase electric motor, with a nominal power of 11 kW, marked as M;
- 4 ON/OFF directional hydraulic valves, cartridge type, marked as DV1, DV2, DV3, DV4, used to control the output of each pump;
- 4 check valves, marked as CV1, CV2, CV3, CV4, used to stop the hydraulic oil to flow back in the output of the pumps when 1, 2 or 3 pumps are used.
- 1 relief valve for the system safety, marked as RV, used to protect the system when pressure limit is exceeded by the load;
- 1 pressure transducer mounted on the system output branch, marked as PT, used to measure the system pressure generated by the load;
- 2 flow meters marked as FM1, FM2; FM2 is used to measure the system output, and FM1 is used to monitor the return flow when the valves DV (1…4) are used, and measure the flow that pass through the relief valve when all the pumps are sending the flow to the load, and pressure from the system is exceeding the relief valve adjusted limit;
- 1 temperature meter marked as TM, used to measure system temperature;
- 1 throttle valve marked as TR, used to generate load in the system;
- 1 return filter marked as RF, used to filter the return oil from the pumps;
- Oil tank marked as T;
- Electric enclosure, which contains all the electric components necessary for the system to work, perform data acquisition, and control the system by using a Programable Logic Controller (PLC);
- Energy meter, used to show the power absorbed from the grid by the electric engine.

The transducers values for pressure (PT), flowrate for the system output (FM2), energy meter (EM), and the electric engine speed are displayed live on the app screen as numeric values or charts. The transducers values for return flow (FM1), and temperature (TM) are showed locally on the system test bench by using 2 display units, and these are not displayed on the result charts.

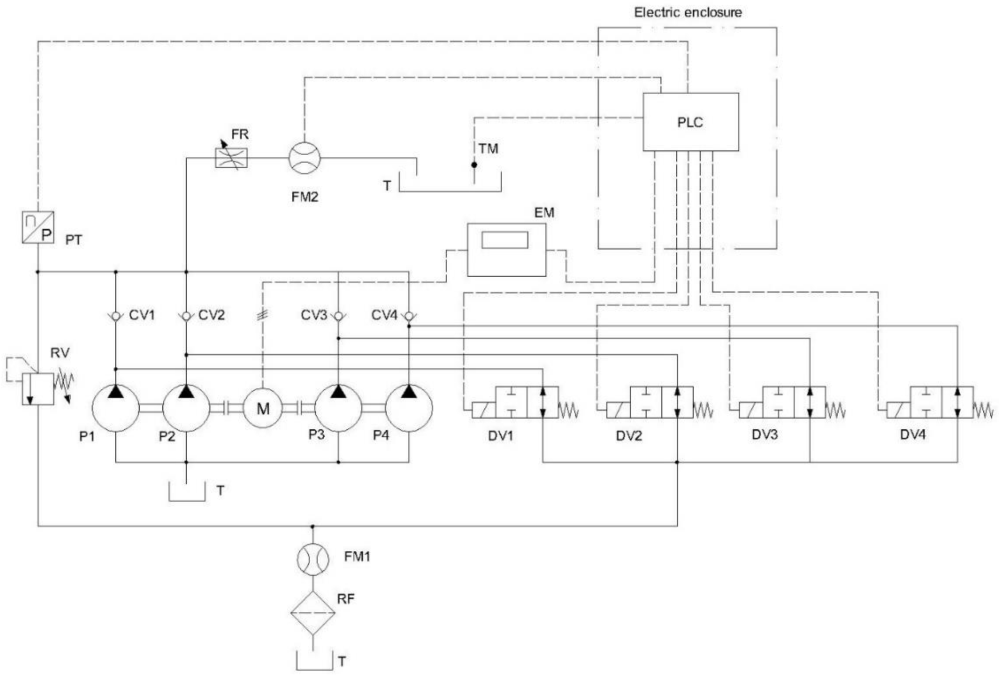


Fig. 2. Hydraulic diagram of the DHPS

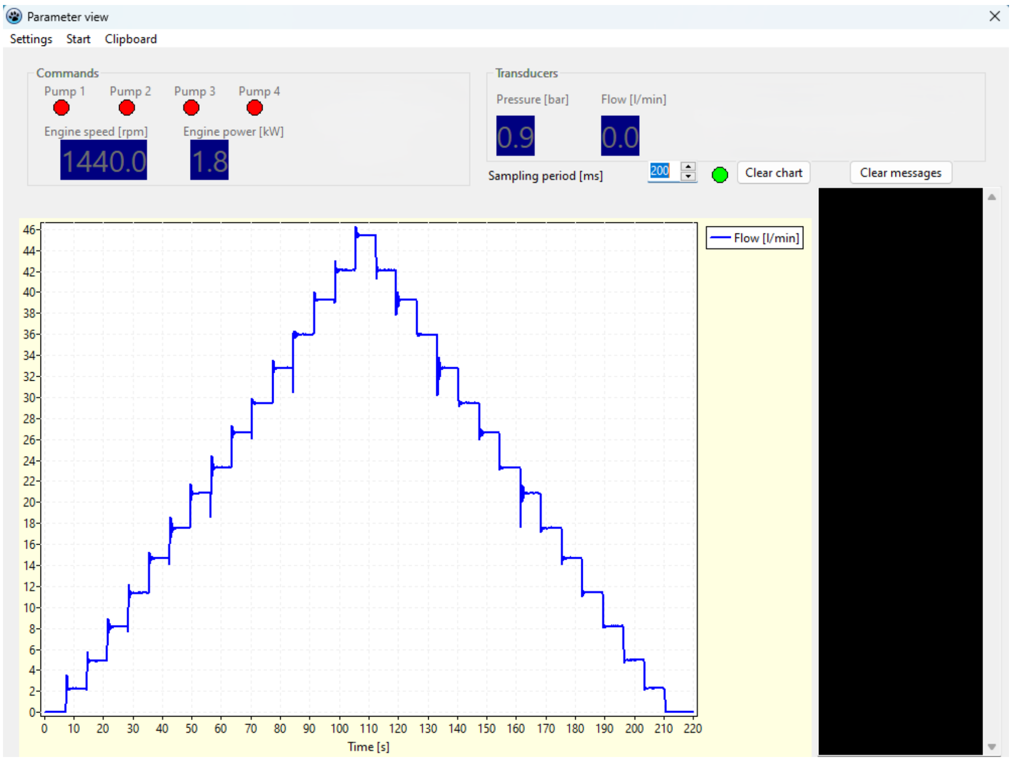


Fig. 3. Application for the digital hydraulic pumping system

Fig. 4. The DHPS test stand

Figure 4 illustrates the DHPS test bench, assembled based on the hydraulic diagram from figure 2.
The system was designed to achieve different flowrates in 15 points with the step of the flow generated by the small pump P1. The number of flowrates that the system can achieve was calculate using the formula: 2^n-1, where *n* is the number of parallel connected pumps; so, 2^4-1 = 15 maximum flowrates.
To enable system operation, we programmed the Programable Logic Controller (PLC) form the electric enclosure, and developed a software application (figure 3) installed on a computer that can control the system function, view numeric value of parameters in real time and build charts also in real time.
The software application is built to do an automatic test on the system using a excel file that commands each of the pumps outputs by sending command signals to the directional valves, in order to obtain each of the 15 points of flowrates that the system can achieve.
The excel file needed by the application to do the automatic test is basically a table with 5 columns and minimum 18 rows (according with the experiment type), defined earlier by the operator.
The experiment was made with the following parameters:

- the time interval for each step was set to 7 seconds, time required for the system to became stable;
- the electric engine rotation speed was set to 1440 rev/min;
- the test was conducted from zero flowrate to maximum flowrate and back to zero flowrate;
- for this test, no load was created at the output of the system;
- the excel table that the application requires to run the test in automatic mode was a table with 5 columns and 34 rows, shown in figure 5.

Time [s]	Pump 1	Pump 2	Pump 3	Pump 4	Engine speed [rpm]
0	0	0	0	0	1440
7	1	0	0	0	1440
14	0	1	0	0	1440
21	1	1	0	0	1440
28	0	0	1	0	1440
35	1	0	1	0	1440
42	0	1	1	0	1440
49	1	1	1	0	1440
56	0	0	0	1	1440
63	1	0	0	1	1440
70	0	1	0	1	1440
77	1	1	0	1	1440
84	0	0	1	1	1440
91	1	0	1	1	1440
98	0	1	1	1	1440
105	1	1	1	1	1440
112	0	1	1	1	1440
119	1	0	1	1	1440
126	0	0	1	1	1440
133	1	1	0	1	1440
140	0	1	0	1	1440
147	1	0	0	1	1440
154	0	0	0	1	1440
161	1	1	1	0	1440
168	0	1	1	0	1440
175	1	0	1	0	1440
182	0	0	1	0	1440
189	1	1	0	0	1440
196	0	1	0	0	1440
203	1	0	0	0	1440
210	0	0	0	0	1440
217	0	0	0	0	1440
224	0	0	0	0	1440

Fig. 5. The table for the automated experiment

3. Results and Discussion

Figure 6 illustrates a capture from the control app screen where one can see a chart with four curves which describes the system parameters, such as Electric engine speed (in rpm, with color orange), Pressure (in bar, with color red), Flowrate (in l/min, with color blue), and Active power (in kW, with color olive), absorbed from the grid by the electric engine during the experiment.
As displayed in figure 6, one can see that the system output achieves a number of 15 flowrates on the ascendent and the same number on the descendent part of the flowrate trace. The reason that the experiment was made from minimum flowrate to maximum flowrate and back again to minimum flowrate was to prove that the system repeatability is very good and it achieves the same values of flowrates on each part of the chart. In the same figure one can see that the maximum flowrate that the system can achieve is approximatively 44 l/min and the minimum flowrate is approximatively 2 l/min, while the step for each flowrate between minim to maxim is approximatively 2 l/min.

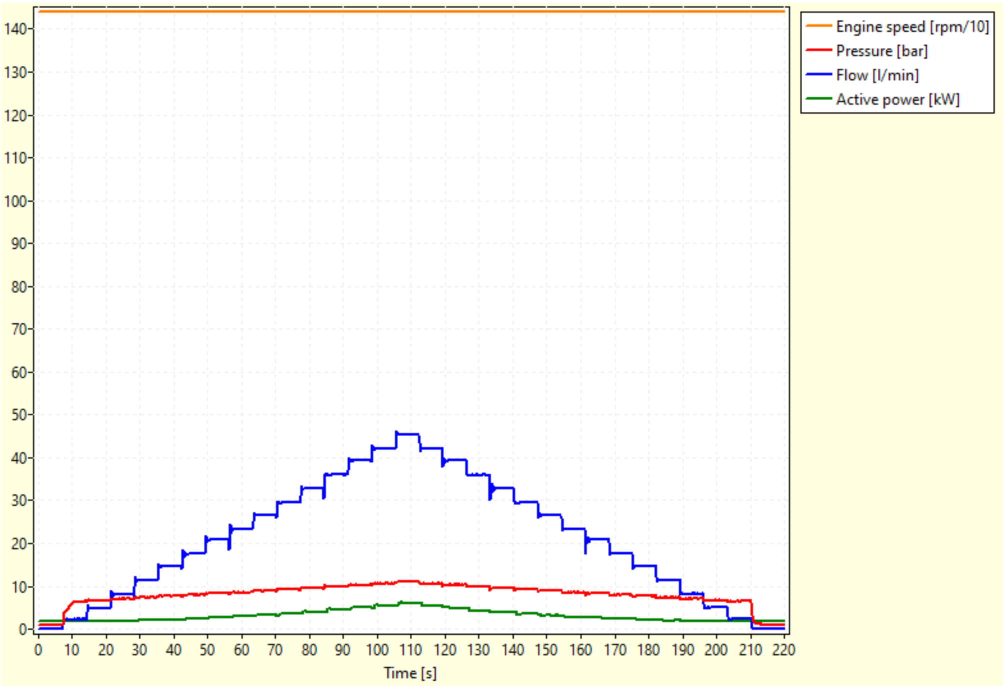


Fig. 6. Experimental results showing traces for engine speed, pressure, flowrate, and active power on the same chart

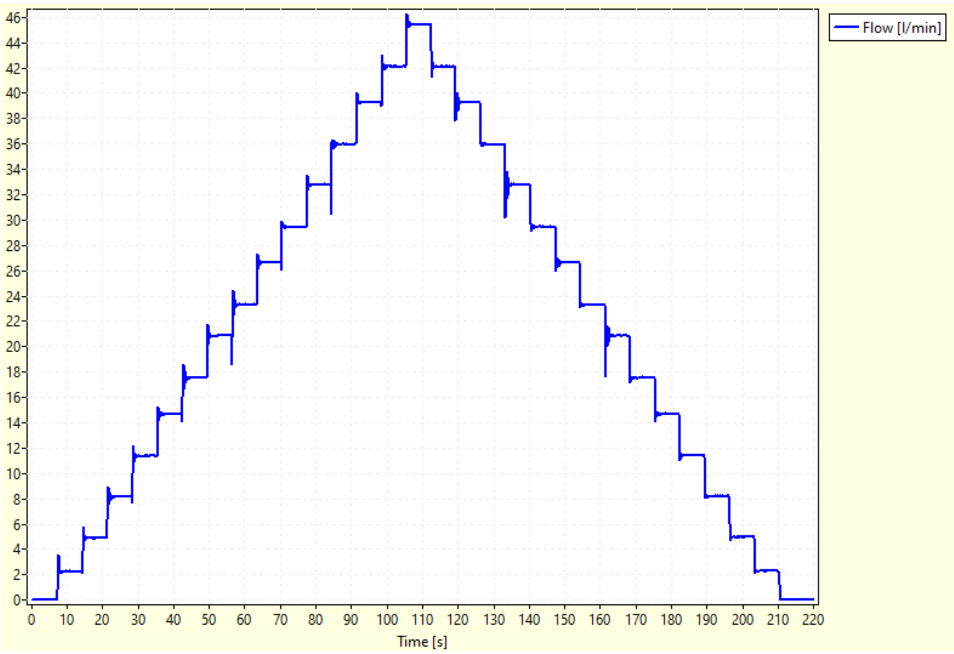


Fig. 7. Experimental result showing only the flowrate trace on the chart

Figure 7 displays a chart with only one trace that shows the value for flowrate. The reason that we suppressed the other 3 traces from figure 6 is to properly view the flowrate steps and see that when the system is moving on to another step, some peaks are appearing on the chart. Those peaks of flowrates are appearing due to the fluid inertia, and, as one can see in figure 8, those peaks appear also on the pressure trace.

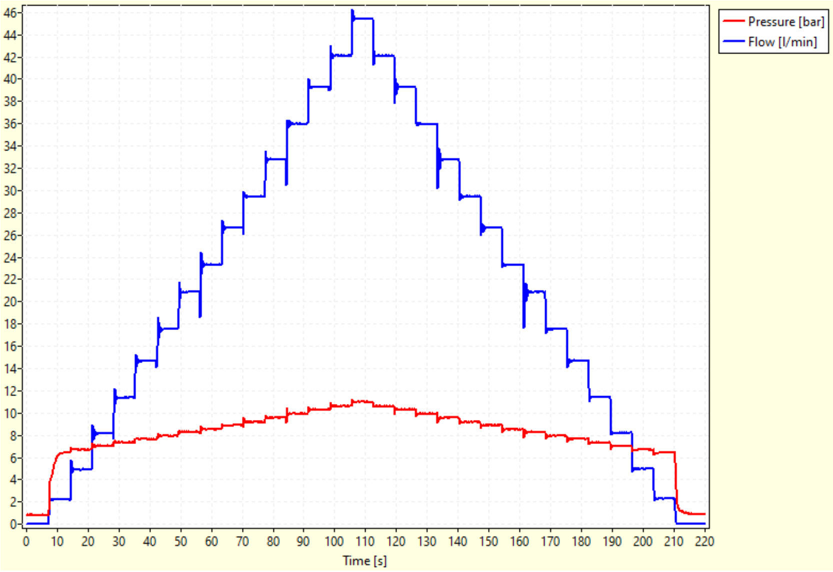


Fig. 8. Experimental results showing the flowrate and pressure traces

Figure 8 illustrates the flowrate and the pressure traces of the experiment, and one can see that both pressure and flowrate have the same number of steps.

4. Conclusions

The system presented in this paper proves that a flowrate variation can be successfully achieved with simple components and can be used in hydraulic systems that don’t need many flowrate variations such as the ones provided by proportional and servo systems.
As one can see from figures in the result section, the system has a good repeatability, proven by obtaining the same values for the evaluated parameters for each step on the ascendent and descendent part of the traces.
Based on the results presented above, the digital hydraulic pumping system needs to be optimised to reduce flow and pressure peaks that system have, but this is the subject of another work that will be done in future.
This paper shows that the field of digital hydraulics is expanding rapidly and it is worth to be developed further so that components become more reliable, cheaper, more efficient, and have smaller dimensions than they currently have.

Acknowledgement

This work was carried out through the Core Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of the Romanian Ministry of Research, Innovation and Digitalization (MCID), project no. PN 23 05.

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